PRE-PRINT: Strickland, M. A., M. Dressler, et al. (2010). Third-Generation UHMWPE Wear Algorithms: Theory and Application. World Congress in Biomechanics, 6th Meeting. Singapore 1st-6th August 2010

Third-Generation UHMWPE Wear Algorithms: Theory and Application

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For implants utilising traditional metal-on-polymer articulations, wear of ultra-high molecular weight polyethylene (UHMWPE) remains an import design concern due to potential problems of osteolysis and mechanical failure. Early first-generation wear concepts [1] have been widely supplanted by a range of second-generation models specific to UHMWPE, reflecting the 'cross-shear' dependency associated with multi-directional sliding [2]. However, these models have limited predictive power [3]; they are acausal and scale-independent. We propose a more robust third-generation framework for implementing wear algorithms. This model is flexible, to incorporate different concepts from existing wear theories, and could be applied to various wear-prediction scenarios from pin-on-disc (POD) testing to different implant devices such as hips, knees, shoulders, etc.

In this model, wear is considered to be a function of the time-history of previous sliding events, and as such the sum-effect of previous time-steps must be progressively integrated. We achieve this by modelling a polar-vector array (PVA) to represent surface 'strain hardening'; each new sliding motion encountered is firstly evaluated to determine an instantaneous wear-rate contribution, and secondly evaluated to determine the corresponding 'modifier' strength term to re-shape the PVA. This gives a robust, causal and scale-sensitive basis for wear-prediction. Further, recognising that there is still much debate about the key influences affecting wear (e.g. the relationship between contact pressure and wear [4, 5]) we present this framework in a 'generic' form. It is possible to customise this generic third-generation framework around any of the different proposed second-generation theories, giving flexibility for ongoing investigations into the causes of UHMWPE wear. This allows our third-generation wear approach to build on, rather than discard, the learning from second-generation theories.

We demonstrate this algorithm using POD test results from the literature [6, 7]. We compared predicted wear rates for conventional and cross-linked PE, and discovered that although the POD-derived constants give appropriate order-of-magnitude estimates for wear (~4.7mm^3/MCycle predicted vs ~4.1mm^3/MCycle experimental), they appear to exaggerate the differences observed *in-vitro* (with conventional PE wear ~2.5x higher) – suggesting additional factors are complicit under TKR loading conditions. Further work is needed to robustly verify these new theories – in particular extensive further testing against *in-vitro* test results from experimental wear simulators, similar to [3]. It is postulated that there are still phenomena outstanding which must be incorporated within this generic framework to further increase predictive power. However we hope that by providing this improved approach, other researchers in different areas can apply this framework to their existing models, so advancing the science of pre-clinical wear prediction.

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